

# Tau Identification at the Tevatron



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for the CDF and DØ collaborations



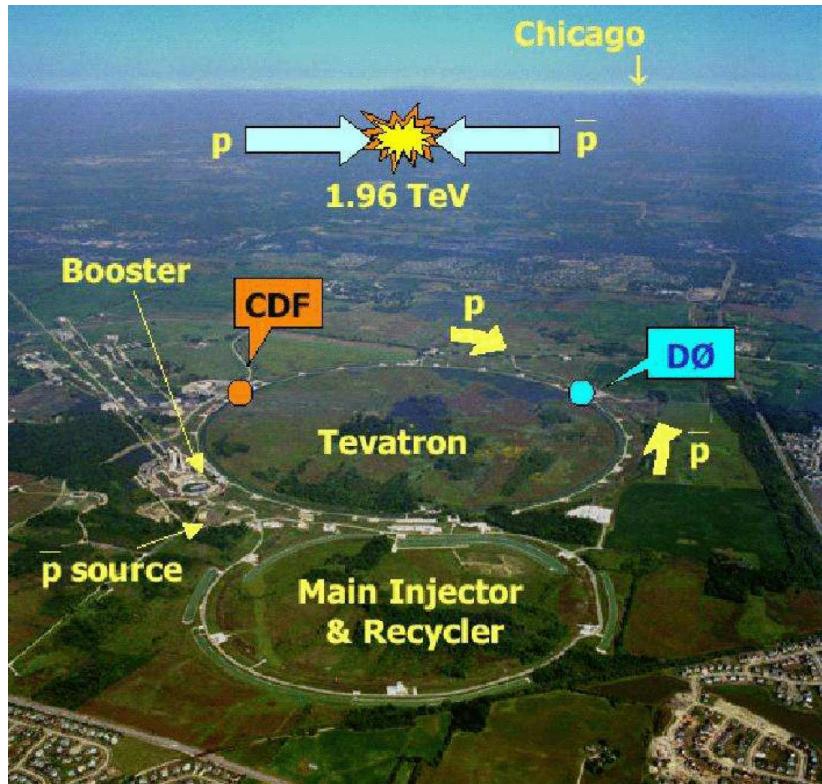
Hadron Collider Physics, Duke University  
May 25, 2006



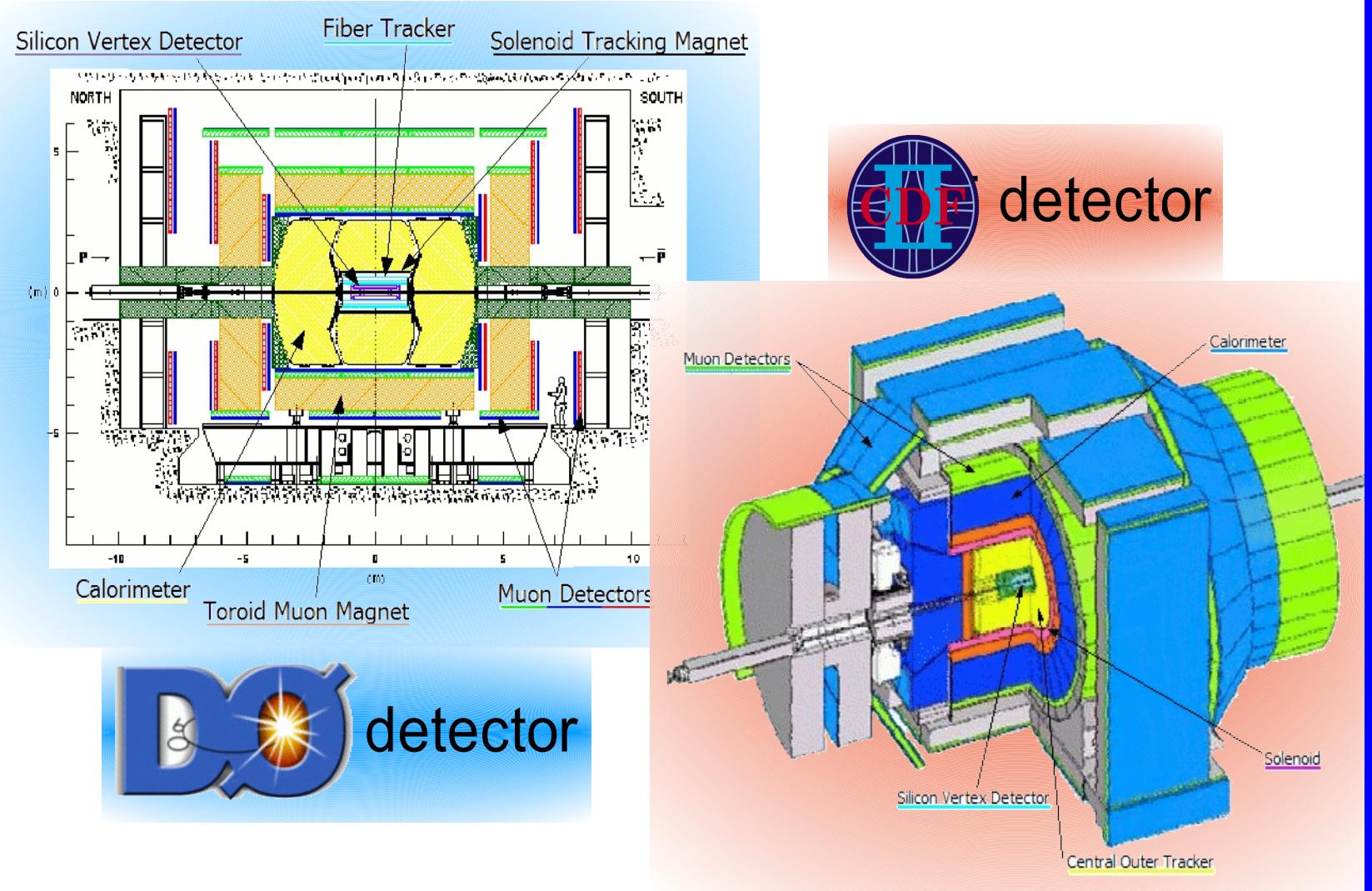
# OUTLINE

- Motivation
- Tau properties
- Tau Triggers
- Tau Reconstruction
- Background reduction
  - Cuts CDF
  - Neural Network DØ
- Some Physics Results
- Conclusion

## Fermilab



# DETECTORS





## Why taus?



- Increase acceptance for channels with leptons.  
Assuming same  $\epsilon$  for any lepton id:
  - Single lepton channel  $\times 1.5$
  - 2 lepton channel  $\times 2$
  - 3 lepton channel  $\times 3$
- Largest coupling of Higgs to leptons is to  $\tau$ 's
- Minimal SUSY models with large  $\tan\beta$  favor decays to  $\tau$ 's and lightest scalars are 3rd generation partners.
  - $H^\pm$  decay to  $cs$  and  $\tau\nu$
  - $\tilde{\tau}$  decay to  $\tau + \text{LSP}$
  - SUSY Higgs {h, H, A} cross sections and couplings to  $\tau\tau$  increase with  $\tan\beta$
- 3rd generation lepto-quarks



# Tau Properties



Mass=1.78 GeV, short lifetime  $c\tau = 87 \mu\text{m}$

Spin 1/2 => decay angle distributions depend  
on  $\tau$  polarization

Final State	B.R. (%)	Decay type	
$e\nu_e\nu_\tau$	17.8	Leptonic	$\tau_e$
$\mu\nu_\mu\nu_\tau$	17.4		$\tau_\mu$
$\pi(/K)\nu_\tau$	11.8	1-prong	$\tau_h$
$\pi(/K) \geq 1\pi^0\nu_\tau$	36.9		
$\pi\pi\pi \geq 0\pi^0\nu_\tau$	13.9	3-prong	



# Tau Triggers



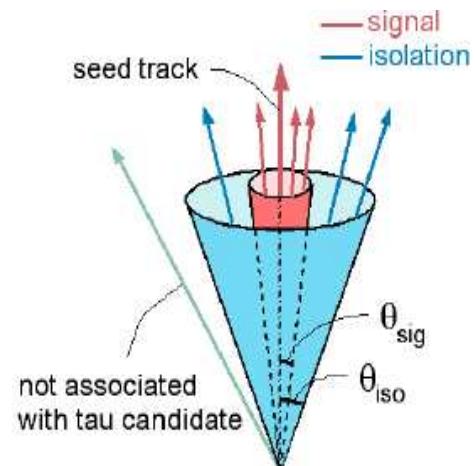
- Both experiments have single- $\tau_h$  and di- $\tau$  triggers
- Di- $\tau$  triggers may be  $\mu+\tau_h$ ,  $e+\tau_h$  or  $\tau_h+\tau_h$
- CDF single  $\tau_h$  is single track at L2 plus isolation around track at L3.
- DØ has a similar  $\tau_h$  trigger adding cal. tower at L1 and loose NN cut at L3
- CDF uses  $\tau_h + \cancel{E}_T$  for  $W \rightarrow \tau\nu$ , and single  $e$  (isolated track + EM tower) or  $\mu$  (isolated track+ $\mu$  in muon system) in coincidence with  $\tau_h$  trigger for  $Z \rightarrow \tau_e\tau_h$  and  $H \rightarrow \tau\tau$ .
- DØ also uses single  $\tau_h + \cancel{E}_T$  for  $W \rightarrow \tau\nu$ . Analyses with di- $\tau$  triggers are at early stages. For  $Z \rightarrow \tau_\mu\tau_h$  and  $H \rightarrow \tau\tau$  single  $\mu$  and single  $e$  triggers are used.

All  $\tau$  triggers add up to 2 Hz to tape @ $10^{32}/\text{cm}^2/\text{sec}$ .



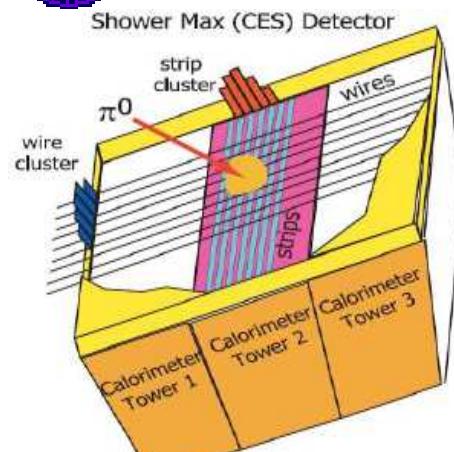
## Tau Reconstruction

- Start with seed track,  $p_T > 6 \text{ GeV}$ ,  $|\eta| < 1.0$ .
- Require cal. tower hit by seed track have  $E_T > 6 \text{ GeV}$
- Add contiguous towers with  $E_T > 1 \text{ GeV}$
- Maximum number of towers=6
- Tau cone defined by cluster energy  $E_{clu}$
- Half angle of cone  $\theta_{iso} = 30^\circ$ ,  $\theta_{sig} = 50 - 175 \text{ mrad}$
- Isolation annulus between  $\theta_{iso}$  and  $\theta_{sig}$
- 1 or 3 tracks, charge=1 in  $\theta_{sig}$
- reconstruct  $\pi^0$ 's
- $M(\text{tracks}, \pi^0) < 1.8 \text{ GeV}$

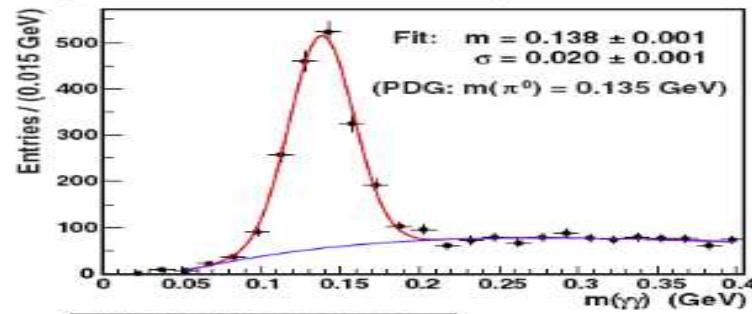




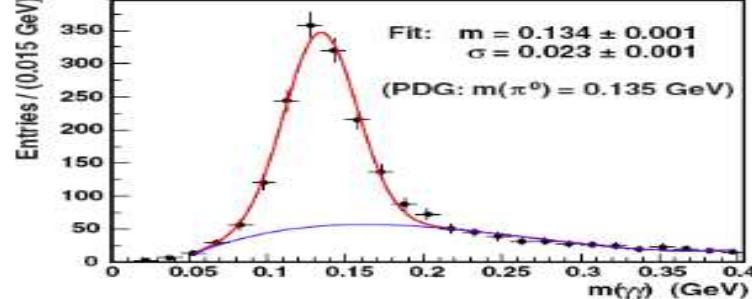
# $\pi^0$ Reconstruction



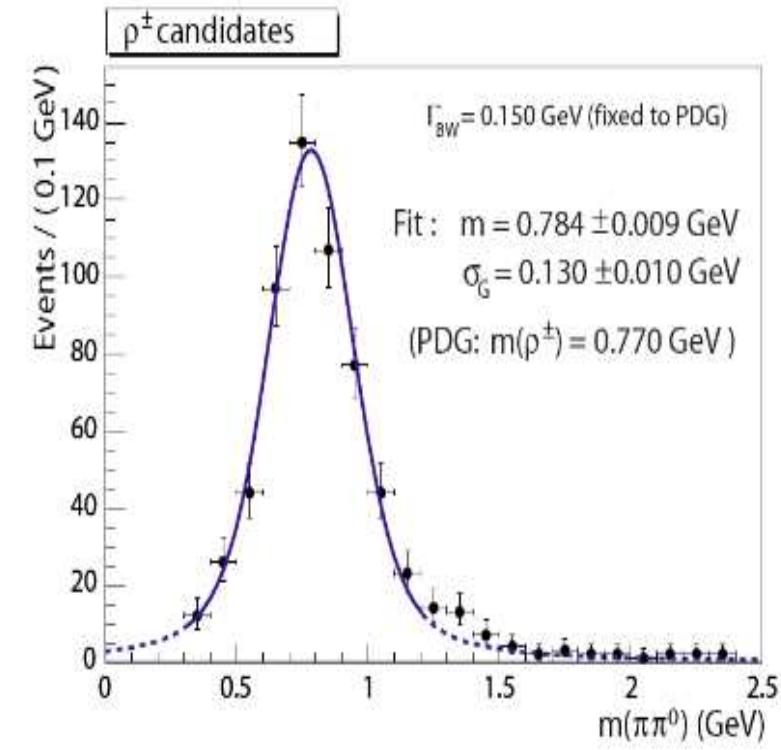
Photons in different towers



Photons in same tower



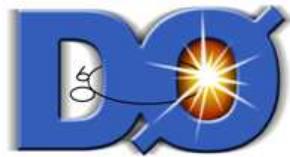
Proportional strip/wire drift chamber  
6 rad. lengths inside EM cal.  
used for  $e$  id and  $\pi^0$  reco.  
Spatial resolution  $O(2\text{-}3$  mm)





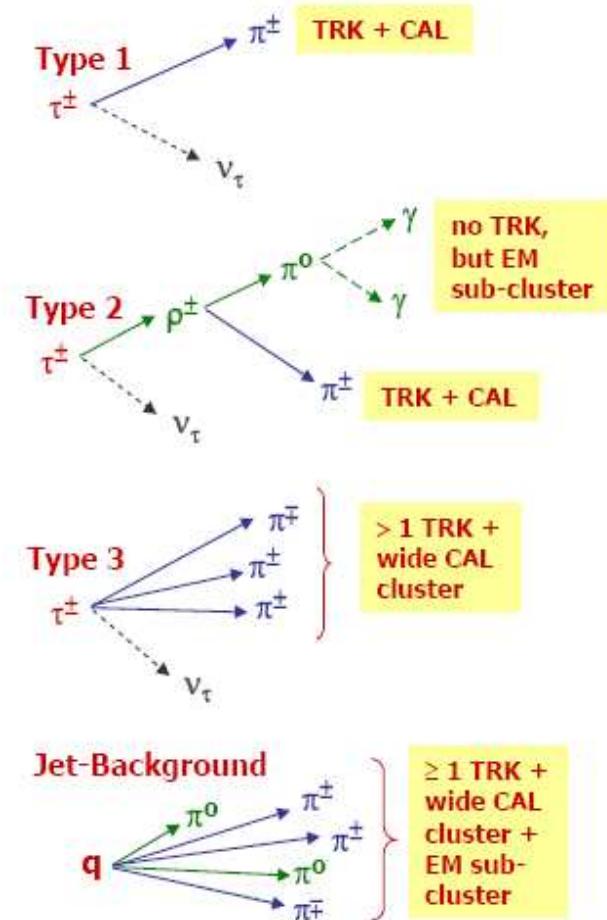
## Tau candidate

- **Calorimeter Cluster:** Simple cone algorithm, cone size  $R = 0.3$ , isolation cone size  $R_{iso} = 0.5$ , require cluster  $rms < 0.25$ .
- **EM Sub-clusters:** nearest neighbour algorithm in EM3 layer. Calorimeter has 4 EM layers, shower maximum is in EM3. EM cells in other layers and preshower hits attached to found EM3 cluster. EM3 cluster energy  $> 800$  MeV.
- **Tracks:** likely to come from a  $\tau$  decay and track  $p_T > 1.5$  GeV



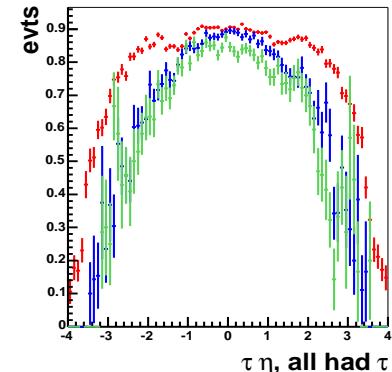
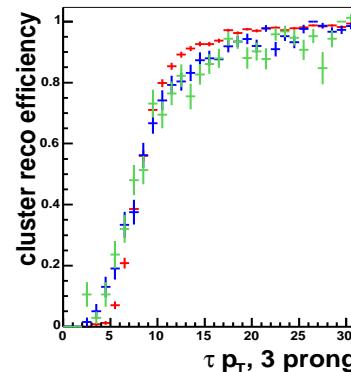
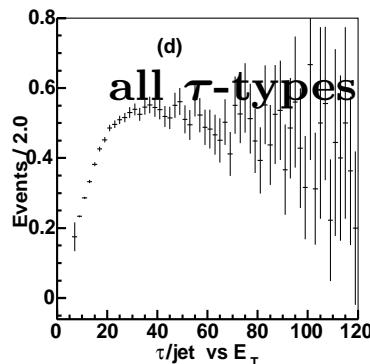
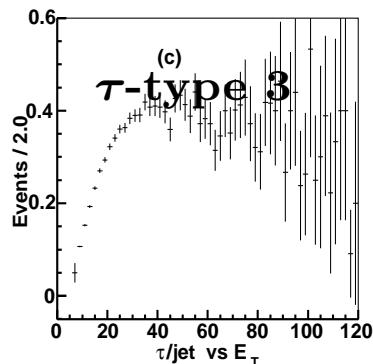
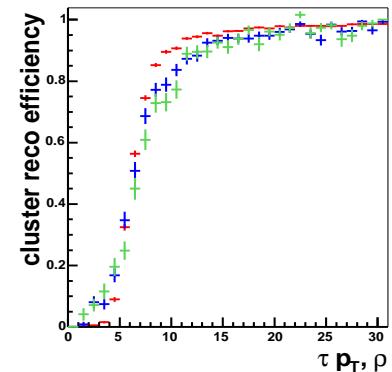
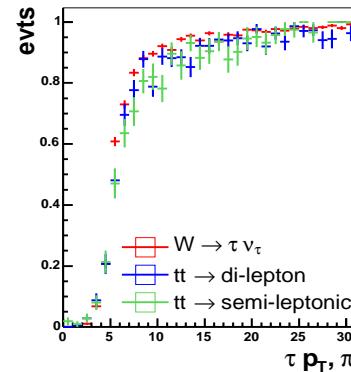
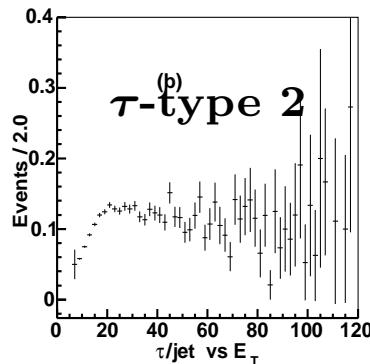
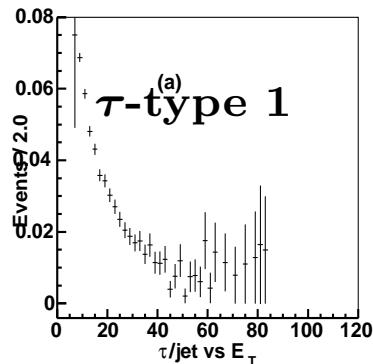
Three  $\tau$ -types:

1. one track + cal. cluster,  
no EM sub-clusters
2. one track + cal. cluster  
and  $> 0$  EM sub-clusters
3.  $> 1$  track + cal. cluster  
 $+ \geq 0$  EM sub-clusters



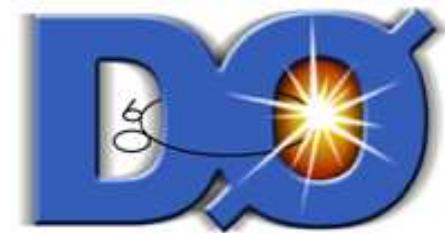
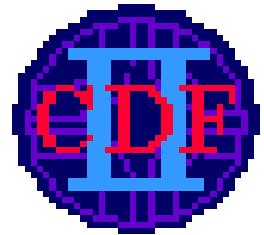


## Reconstruction Efficiencies of $\tau$ candidates



Jets

$\tau$

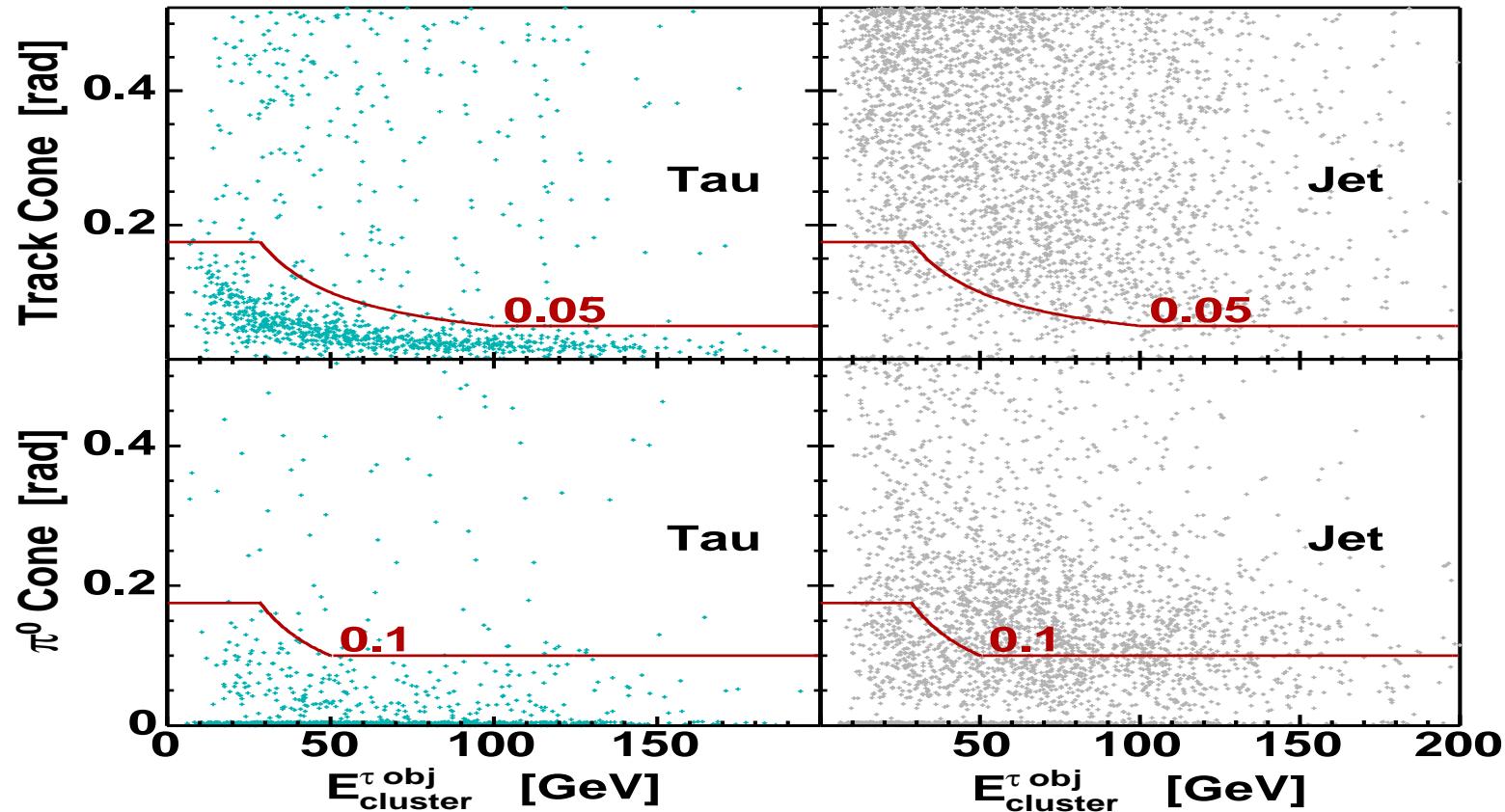


## Background Reduction

- CDF cuts
- DØ Neural Network



## Jet- $\tau$ separation Shrinking cones



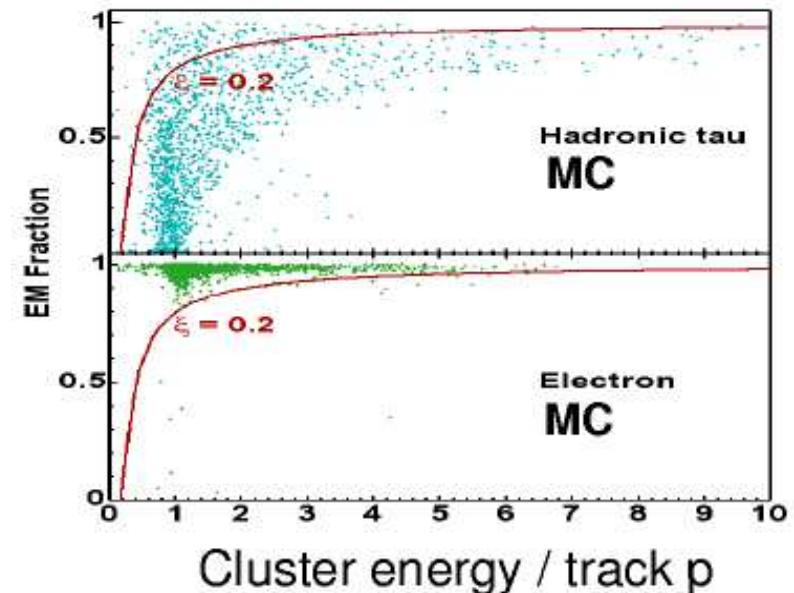
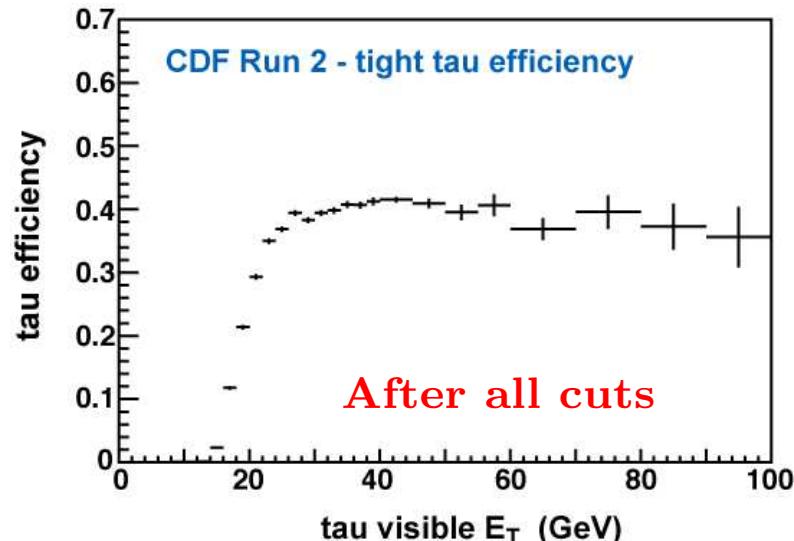
Isolation cuts: no  $p_T^{\text{trk}} > 1.0$  GeV, no  $p_T^{\pi^0} > 1.0$  GeV



## $e - \tau$ separation

### Anti-electron veto

$$\xi \equiv \text{Had Energy} / \sum p_{trk} > 0.2$$



Efficiency ( $\epsilon_h$ ) is for  $\tau_h$

Total  $\tau$  efficiency

$$\epsilon = \epsilon_h \times 0.65$$

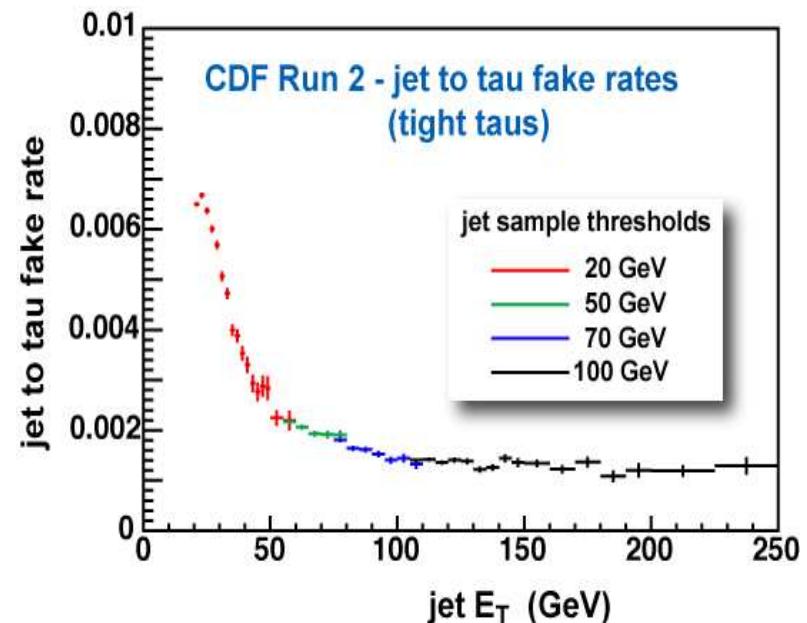
$$\epsilon = 26\% \text{ for } E_T^{vis} > 25 \text{ GeV}$$

# Tau fake rates

Use QCD events selected by jet triggers

$E_T > 20, 50, 70, 100 \text{ GeV}$

$\epsilon$  varies from 0.65% to 0.1%



efficiencies (%)

	$E_T = 20 \text{ GeV}$	$E_T = 25$	$E_T = 50$
$\tau$	16	26	27
jets	0.65	0.4	0.2



## NN variables

- isolation parameters:  $caliso = (E_T^\tau - E_T^{core})/E_T^{core}$ ,  
 $trkiso = \Sigma p_T^{\tau_{trk}} / \Sigma p_T^{\tau_{trk}}$ ,  $em12isof = (E^{EM_1} + E^{EM_2})/E^\tau$
- calorimeter shape parameters:  $rms_\tau$ , *em fraction*, *hadronic fraction*,  $profile = (E_{T_1} + E_{T_2})/E_T^\tau$ , *em profile*= $E_T$  *EM subclusters*/ $E_T^{EM_3}$
- cal. - track correlations:  $E_T^\tau / (E_T^\tau + \Sigma p_T^{\tau_{trk}})$  ,  $\delta\alpha$  angle between  $\Sigma\tau$ -tracks and  $\Sigma EM$ -subclusters

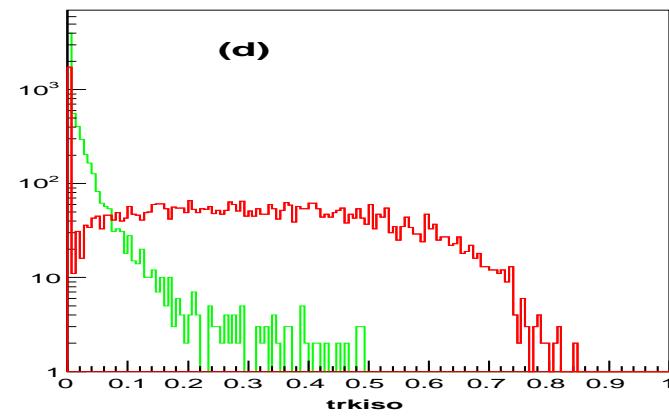
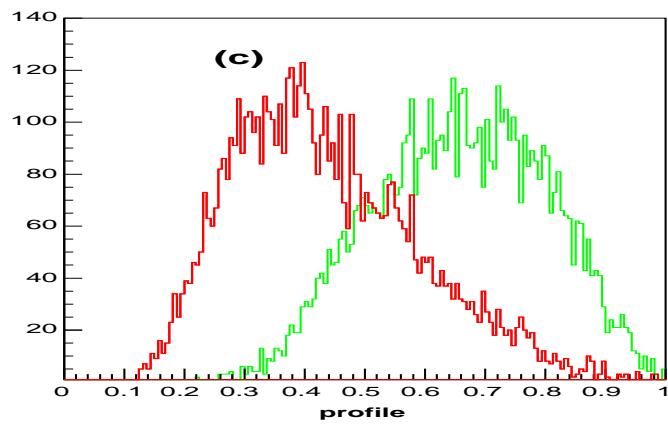
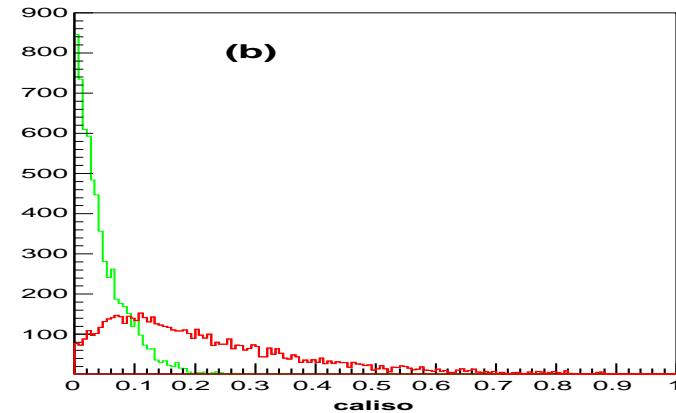
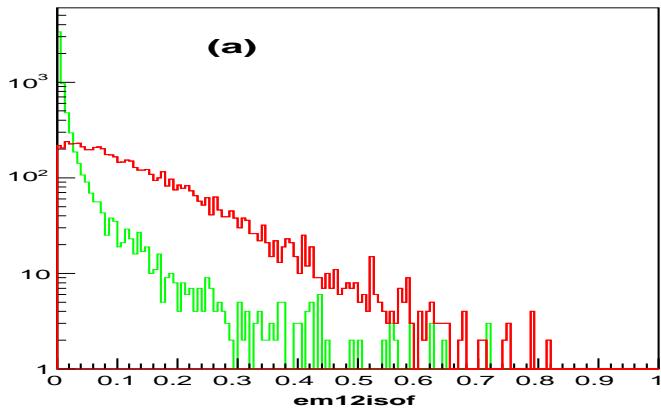
where  $\tau_{trk}$  ( $trk$ ) are tracks associated (unassociated) with  $\tau$ ,  
 $E^{EM_i}$  is  $E$  in  $i^{th}$  layer of EM calorimeter. Cal. cone size  
 $R < 0.5$ , core  $R < 0.3$

Neural Networks (1,2,3 and e) trained with:

- signal:  $\tau$  MC for  $NN$  and  $NN_e$  ( $\tau$ -type 2 only)
- backgrounds: jets from data ( $NN$ ),  $e$  MC ( $NN_e$ )



## Some NN input variables for $\tau$ -type 1, signal (MC $\tau$ ) and background (jets from data).



(a)  $em12isof$ , (b)  $caliso$ , (c)  $profile$ , (d)  $trkiso$



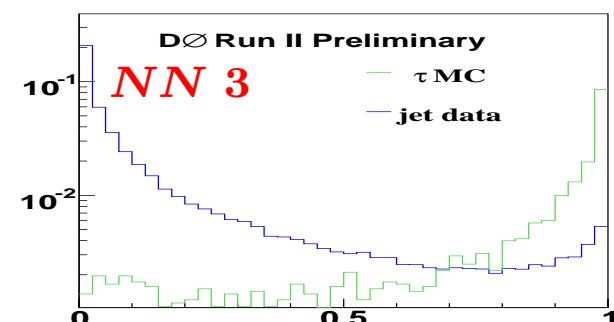
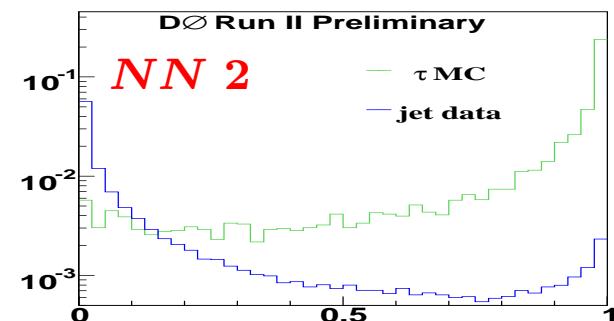
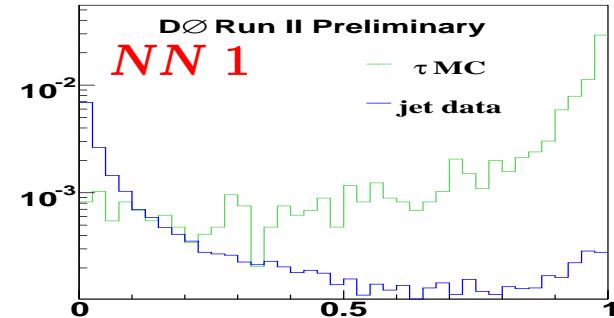
# Jet- $\tau$ separation

efficiencies (%)

$E_T^\tau > 15 \text{ GeV}, |\eta^\tau| < 2.5$

$\tau$ -type	1	2	3
jets	1.5	10	38
$\tau$	9.1	50	20
$NN > 0.9$			
jets	0.04	0.20	0.80
$\tau$	5.8	37	13

Note:  $NN \rightarrow 1$  for signal  
 $NN \rightarrow 0$  for bkg





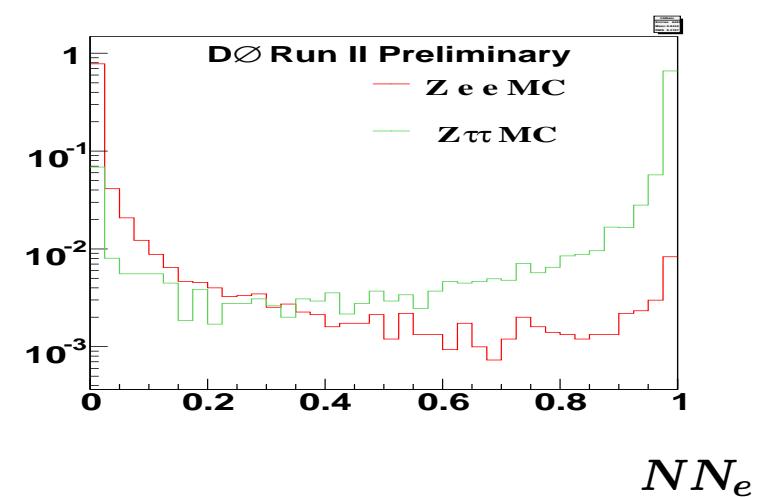
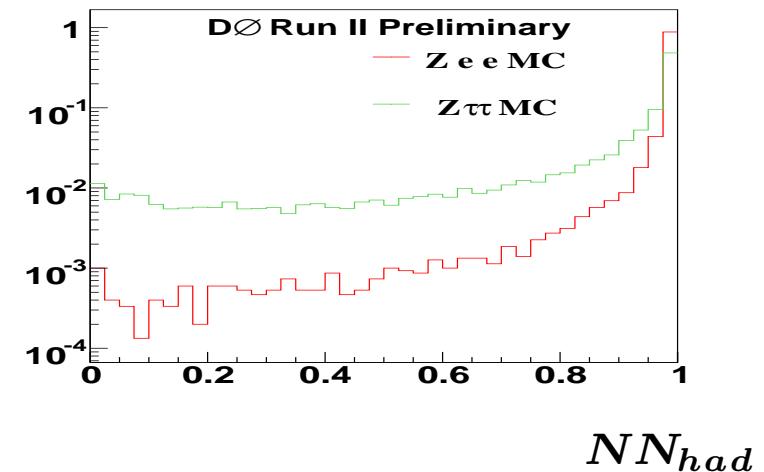
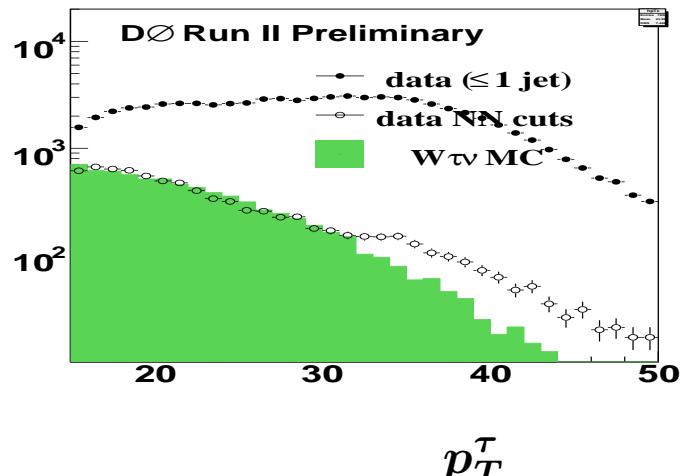
## e- $\tau$ separation

efficiencies (%)

$20 < E_T^\tau < 40, |\eta^\tau| < 2.5$

$\tau$ -type 2  $\rightarrow$  hadrons only

	$NN > 0.9$	$NN_e > 0.5$
$e$	98	3.4
$\tau$	34	30



# μ-τ separation



efficiencies (%)

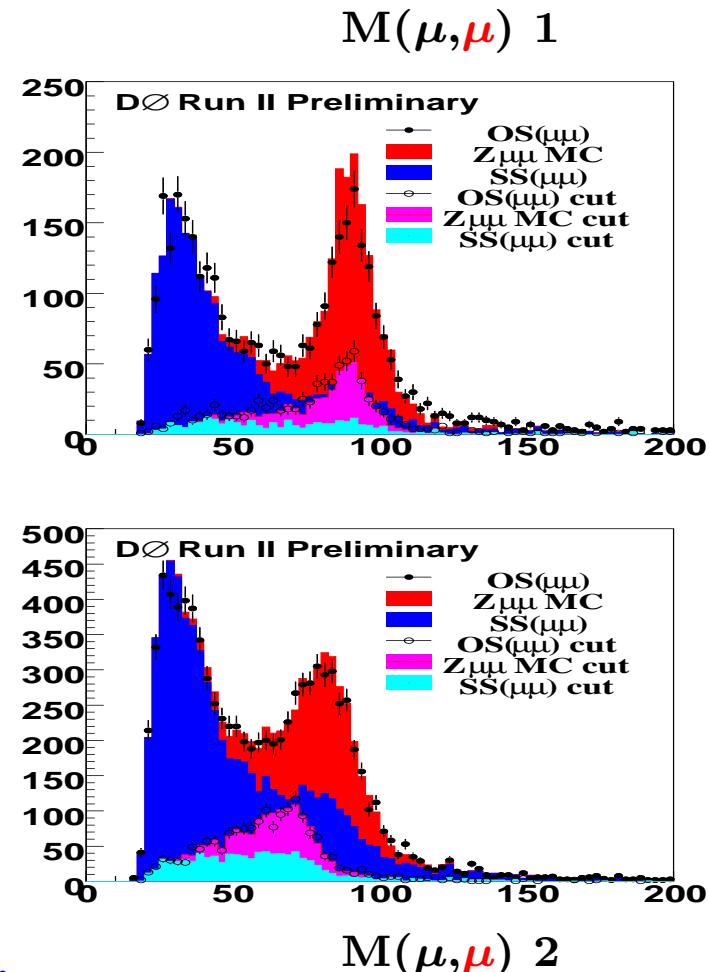
$$p_T^{\tau_{trk}} > 10, |\eta^\tau| < 2.5$$

$NN > 0.9$		
$\tau$ -type	1	2
$\mu$	2.5	3.1
no $\mu$ id	0.4	0.8
$\mathcal{R}_\mu > 0.4$	0.2	0.4
$\tau$	5.5	35

$\mu \equiv$  misidentified as  $\tau$

$$\mathcal{R}_\mu \equiv E_T^\tau (1 - fch) / p_T^{trk}$$

$fch \equiv E_T$  fraction in CH cal. section





## NN on $\mu + \tau_{h,e}$ data

### Event Selection

$\mu \quad p_T > 12 \text{ GeV} \quad |\eta_d| < 1.7$

only 1  $\mu$

$\tau \quad E_T > 10 \text{ GeV} \quad |\eta_d| < 2.5$

$\mathcal{R}_\mu > 0.4$

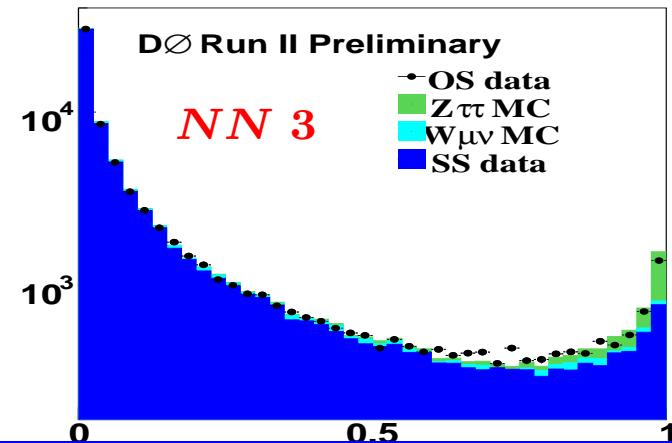
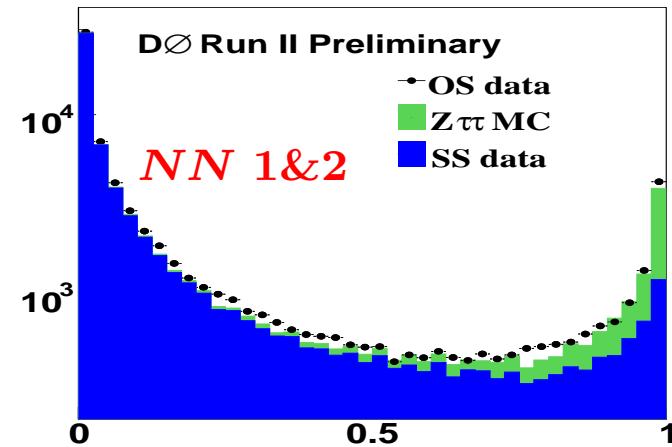
$|\phi_\mu - \phi_\tau| > 2.7$

$\sum$  over many triggers

MC uncorrected for trigger  $\epsilon$

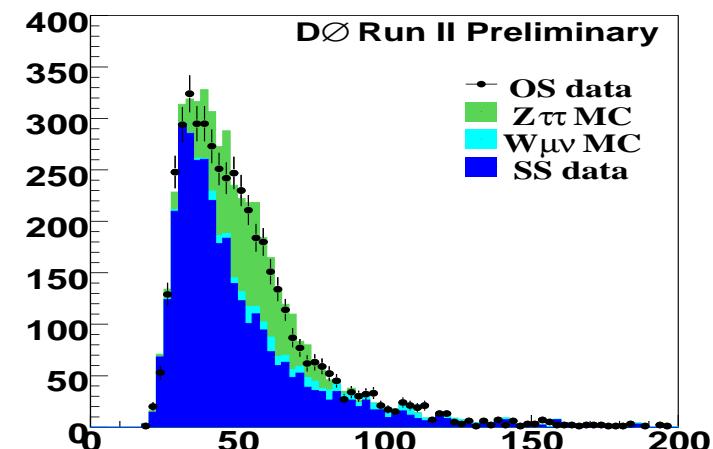
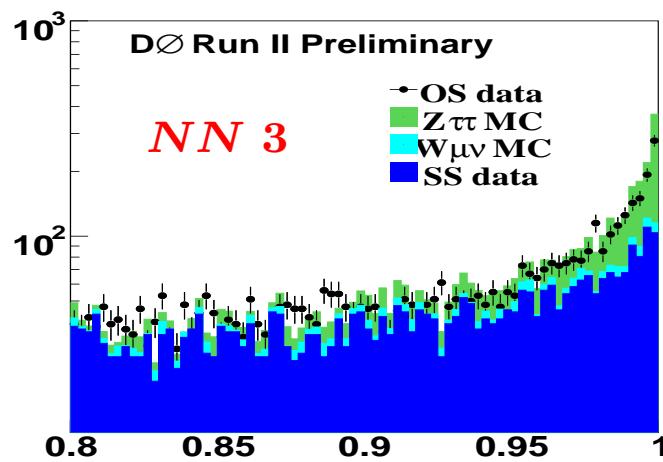
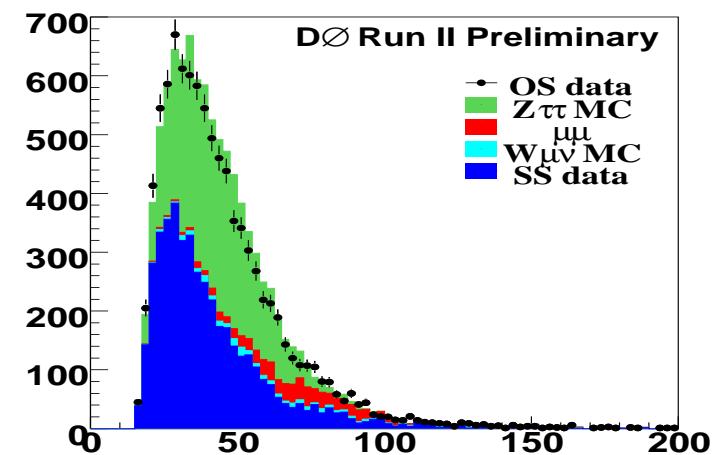
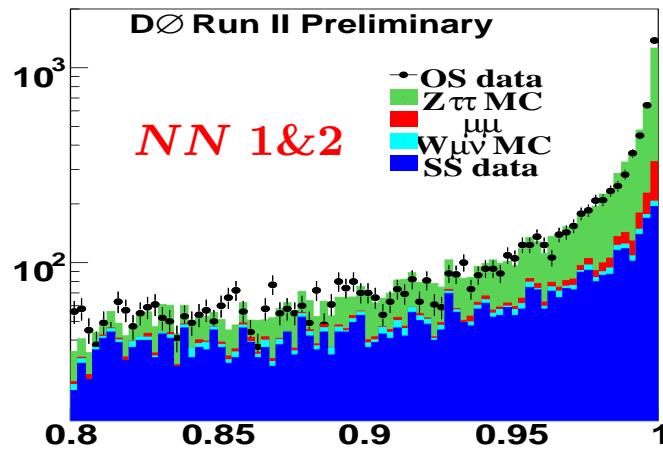
normalized to OS data

$$\int L dt \approx 630 \text{ pb}^{-1}$$



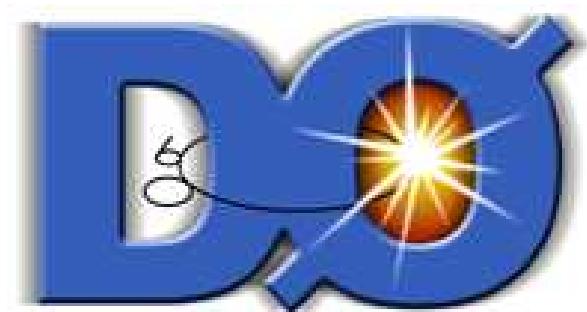
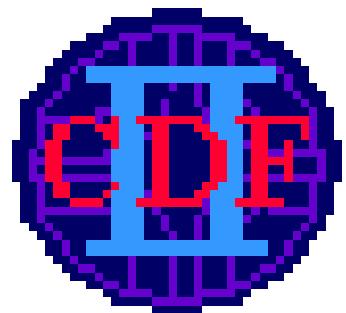


## $\mu + \tau_{h,e}$ data after $NN > 0.8$



$\approx 5000\ \tau$ 's above bckg.

$M(\mu, \tau_{trks})$



# Some Physics Results with $\tau$ 's

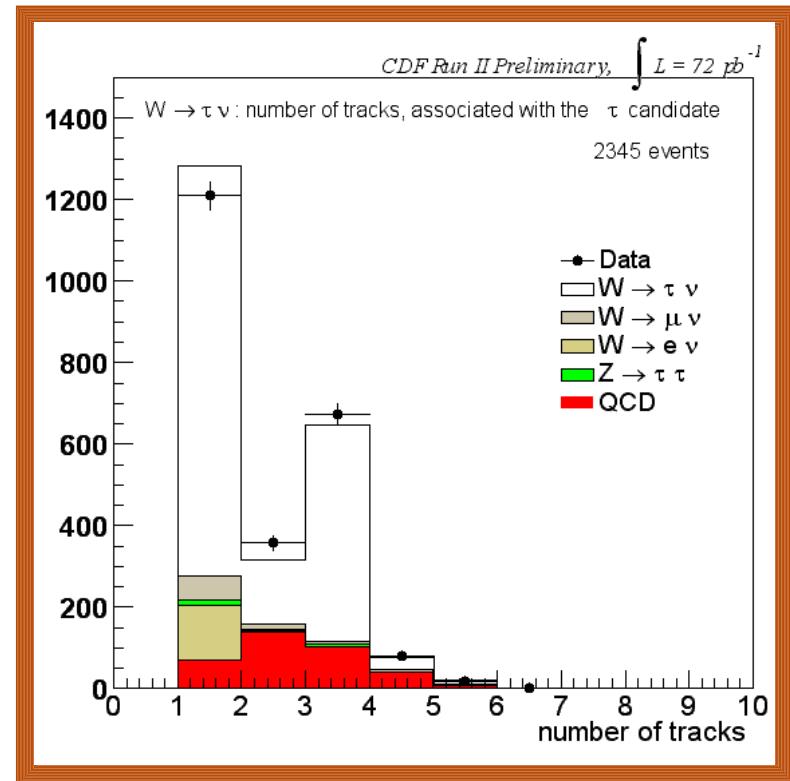


## $W \rightarrow \tau \nu_\tau$ Cross Section

### Event Selection

- $E_T^\tau > 25$  GeV,  $|\eta_\tau| < 1.0$
- $\cancel{E}_T > 25$  GeV
- EM energy fraction  $< 0.8$   
to remove  $e$ 's

2345 events, 26% background  
 $\int L dt = 72 \text{ pb}^{-1}$



$$\sigma \times \text{BR}(W \rightarrow \tau \nu) = 2670 \pm 70_{\text{stat}} \pm 210_{\text{sys}} \pm 160_{\text{lum}} \text{ pb}$$

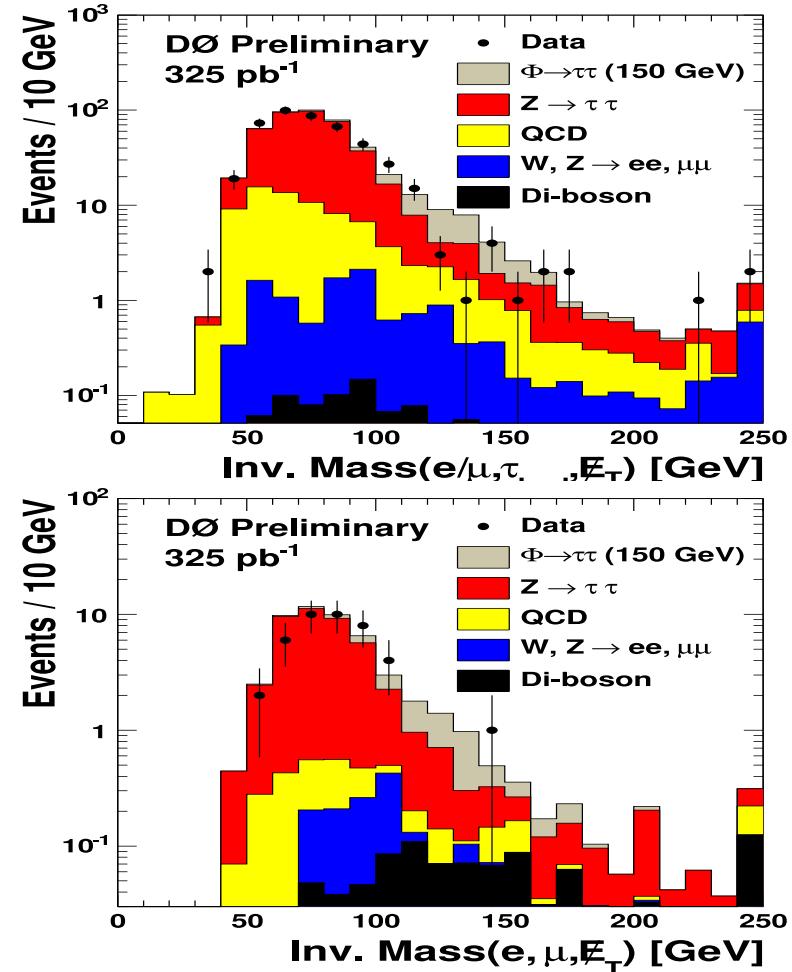
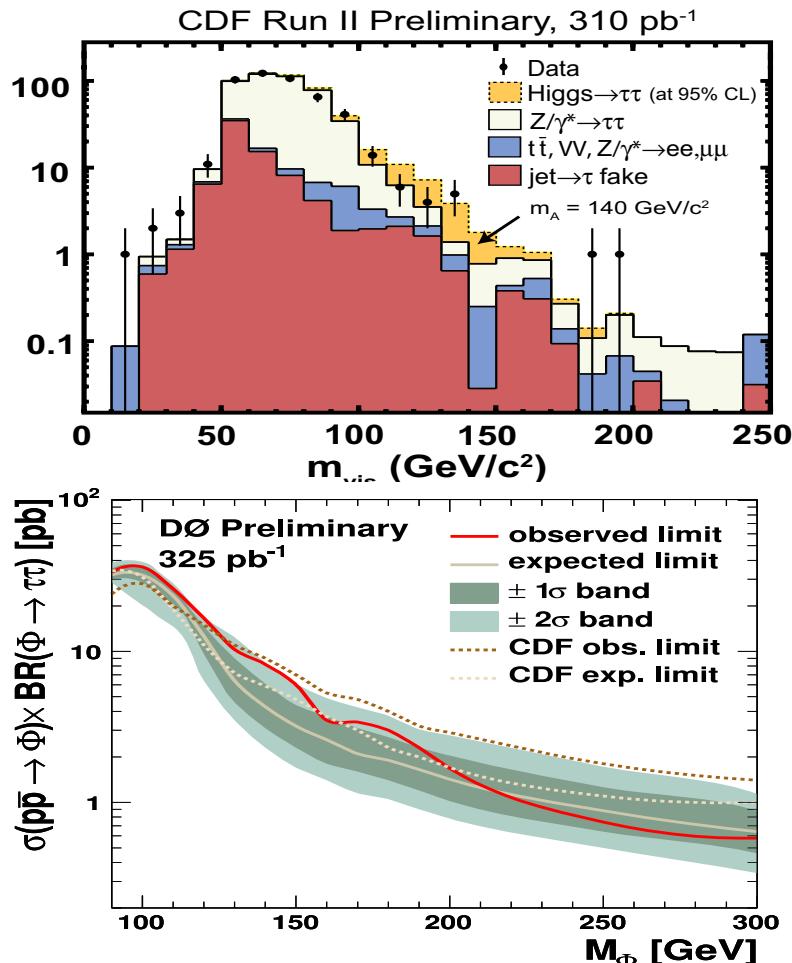
# $Z \rightarrow \tau\tau$ cross section

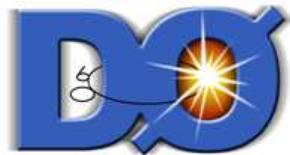
		
channel	$Z \rightarrow \tau_e \tau_h$	$Z \rightarrow \tau_\mu \tau_{h,e}$
Event Selection	$p_T^e > 10, E_T^\tau > 15$ topology cuts	$p_T^\mu > 12, E_T^\tau > 10$ $ \phi_\mu - \phi_\tau  > 2.5, NN > 0.8$
$\int L dt$	$350 \text{ pb}^{-1}$	$226 \text{ pb}^{-1}$
Data	504	2008
Background	$188 \pm 16$	$1084 \pm 69$
$\sigma \cdot BR$	$265 \pm 20_{stat}$ $\pm 21_{sys} \pm 15_{lum} \text{ pb}$	$237 \pm 15_{stat}$ $\pm 18_{sys} \pm 15_{lum} \text{ pb}$

PRD 71, 072004 (2005)



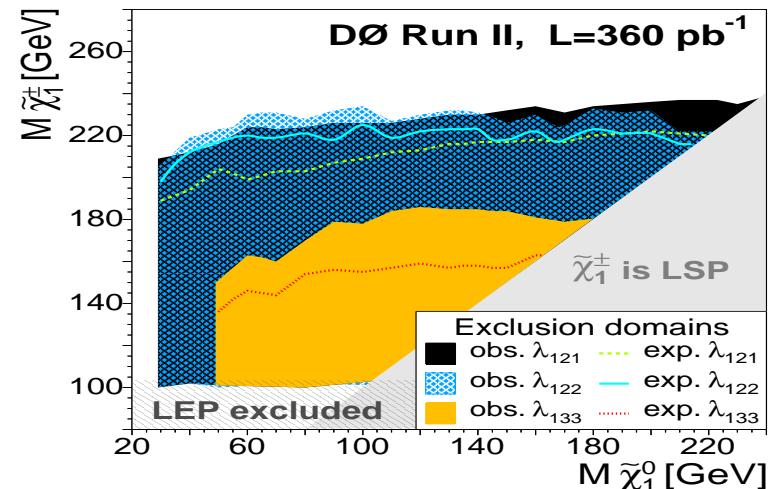
# MSSM Higgs $\rightarrow \tau\tau$ Search



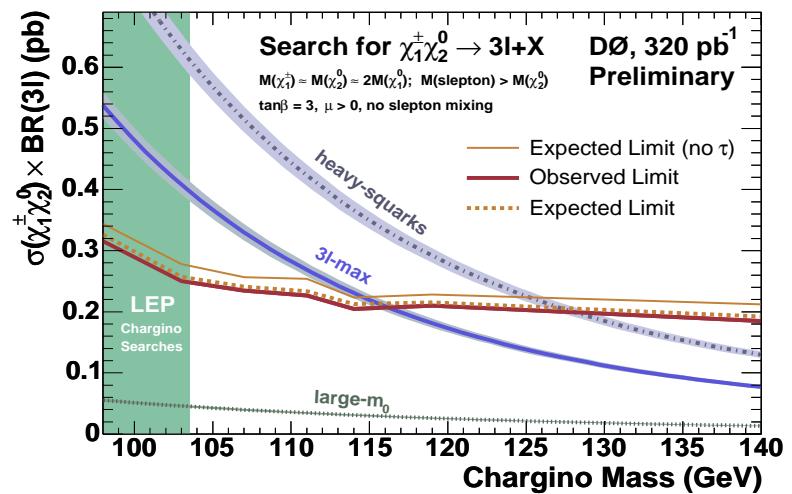


# SUSY Searches in 3l Final States

R-parity violating limits  
assuming  $\lambda_{121} = \lambda_{122} = 0.01$ ,  
 $\lambda_{133} = 0.003$

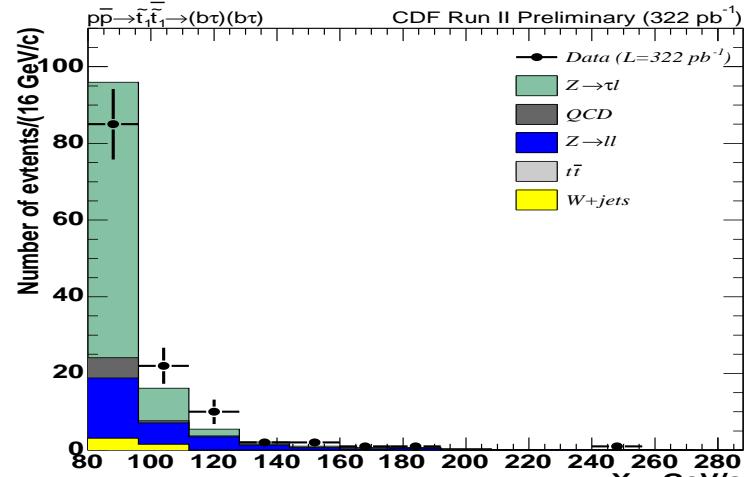
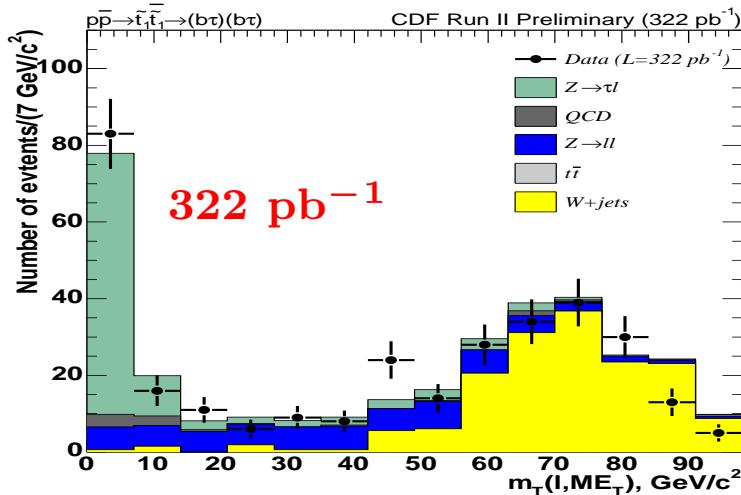


R-parity conserving limits  
assuming  $\tan\beta = 3$ ,  $\mu > 0$   
 $M(\chi_1^\pm) = 2M(\chi_1^0)$   
no slepton mixing





# Limit on $\tilde{t}\bar{t} \rightarrow (b\tau_{e,\mu})(b\tau_h)$ production

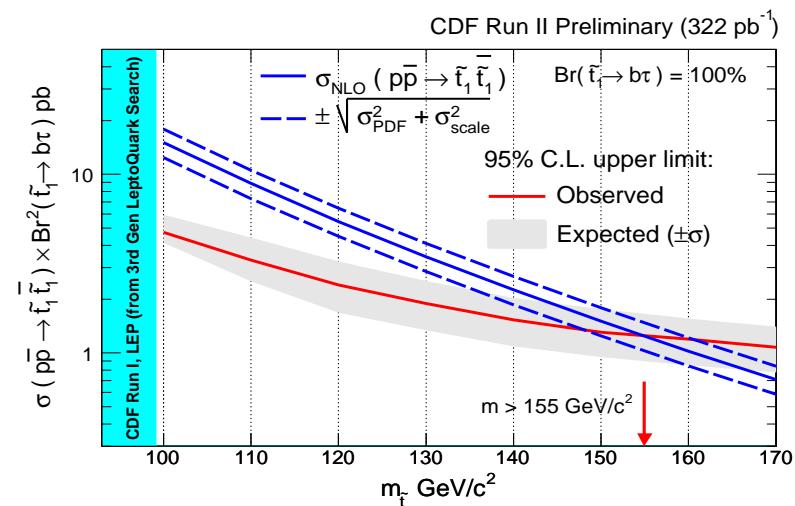


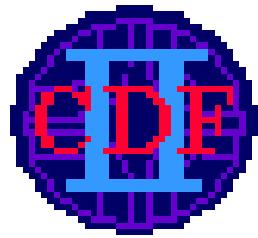
Remove  $Z(ee, \mu\mu)$   
 $(76 < M_\ell\ell < 106 \text{ GeV})$

Remove  $W$  ( $M_T < 35 \text{ GeV}$ )

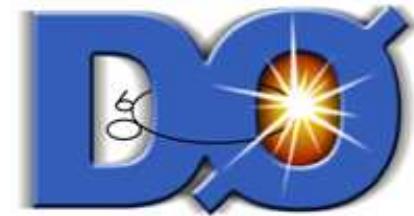
Remove QCD,  $Z(\tau\tau)$   
 $(Y_T > 110 \text{ GeV})$

$m_{\tilde{t}} > 155 \text{ GeV, 95\% CL}$





## Conclusion



- Jet rejections of 1% or better can be achieved with  $\tau$  efficiencies near 50%
- Measurements with  $\tau$  lepton channels at Tevatron can achieve a few % precision.
- Misidentified  $e$ 's and  $\mu$ 's can be reduced to low levels
- Taus are an important handle in the search for new physics at the Tevatron.